Tropical Cyclone Intensity and Structure Changes in relation to Tropical Cyclone Outflow

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LONG-TERM GOALS

The goal of this proposed project is to examine the hypothesis that changes in tropical cyclone intensity and structure depend on: i) vertical alignment of the initial vortex ii) characteristics of the upper-level environment, iii) tropical cyclone structure, iv) phasing of the tropical cyclone and the environmental features, and iv) feedback of the tropical cyclone onto the environment.

OBJECTIVES

The overarching objective of this project is to identify impacts to tropical cyclone structure and intensity throughout the tropical cyclone lifetime. A common factor is the impact of mid- and upper-level environmental conditions that affects formation and intensification of a tropical cyclone. It is hypothesized that during the formation process, the environmental interaction has maximum impact on the vertical alignment of the fledgling circulation and as a mature tropical cyclone impacts on upper-level outflow control periods of intensification or decay. Observational data of the tropical cyclone-environment at upper levels are used in conjunction with numerical simulations to examine the spatial and temporal sensitivities that result in tropical cyclone intensification versus decay, and the mechanisms via which the environmental interaction influences the tropical cyclone primary swirling wind circulation at various stages of intensification.

APPROACH

To achieve the research objectives, analyses and diagnoses of observations are combined with numerical modeling. The project uses observations obtained during TCS-08 using the WC-130J and WP-3B aircraft, which flew at mid- and low-levels in a developing tropical disturbance. Use of the environmental Global Hawk during the Hurricane and Severe Storm Sentinal (HS3) project provides an unprecedented opportunity to diagnose detailed characteristics associated with the upper-level environment of the subtropical and midlatitude regions of the North Atlantic as it pertains to interactions with a poleward-moving tropical cyclone. These observations by the suite of instruments that provide for vertical profiles of environmental parameters allows for identification of key structural characteristics that define upper-level tropical and midlatitude troughs, and magnitude, level, depth, and orientation of tropical cyclone outflow. For the purposes of this study, environmental factors are defined to be most critical at middle and upper levels where the inertial stability of the tropical cyclone vortex is reduced (Merrill 1988a,b). Environmental factors are defined in three interrelated categories:

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- The mid- and upper-level environment into which a tropical cyclone may be moving;
- Vertical wind shear; and
- The upper-level outflow of the tropical cyclone itself.

While these factors have been subjects of numerous research studies, observational data of sufficient spatial and temporal resolution to test valid hypotheses on how environmental factors influence tropical cyclone intensity and structure are lacking.

The analysis and diagnosis of observations are augmented with numerical simulations of observed cases. The purpose of the numerical simulations will be to extend the analysis of observations in time and in space to examine the evolution of physical processes that govern the impact of environmental interactions on tropical cyclone intensity and structure changes. An important objective of the numerical simulations is to assess the relative role(s) of environmental factors and storm-scale factors related to tropical cyclone intensity changes.

WORK COMPLETED

Aircraft-deployed dropwindsondes, flight-level data, and Electra Doppler Radar (ELDORA) data obtained during the TCS08 field program were to specify the detailed structure of a non-developing cloud cluster (TCS025) during TCS08. An ensemble Kalman Filter data assimilation procedure was derived to assimilate ELDORA data for use in high resolution simulations of a non-developing cloud cluster. Additionally, MTSAT IR brightness temperatures were utilized to examine the environment in which TCS025 was embedded and the character of the convective cells that occurred during the lifetime of TCS025.

RESULTS

Based on the observational analysis (Penny 2013), the TCS025 disturbance failed to develop in part due to misalignment of the vortex structure in the vertical. This increased the system-relative flow and allowed outside environmental influences to negatively impact the inner-core thermodynamic structure of TCS025, which weakened subsequent convection. Observations suggested stratiform precipitation processes were more prevalent than convective processes. Without deep convection, spin-up of the low-level circulation was limited and circulation alignment remained poor. It was concluded that the negative feedback between limited convection and poor vertical alignment of the circulation while in the presence of deteriorating environmental conditions inhibited development of the TCS025 disturbance.

To examine sensitivity of spin up to microphysical processes, a multi-physics ensemble revealed that in simulations that exhibited strong convective precipitation processes, the low-level circulation intensified and TCS025 developed. To assess whether the propensity for strong convection and over-development might have been due to an unrealistically aligned vortex structure present in the initial conditions, data assimilation experiments were conducted to improve the initial conditions. The assimilation of all observations, including ELDORA radar observations, provided initial conditions that were more representative of the observed structure of TCS025, which was not aligned in the vertical. Strong convective precipitation processes also occurred in the DART-WRF ensemble mean forecast, and ultimately this led to the development of the TCS025 disturbance. However, the

development was delayed relative to the control simulation. This indicates that the misalignment of the vortex structure in the DWEMF was overcome by convective precipitation processes that eventually led to alignment of the vortex and intensification.

In addition to vortex misalignment, the TCS025 disturbance was adversely impacted by the presence of dry air associated with upper-level cells in the tropical upper-tropospheric trough. Therefore, the upper-level environment was unfavorable for maintaining favorable thermodynamic conditions as the upper- and mid-level dry air was entrained into the TCS025 circulation (Fig. 1) and reduced the convective available potential energy. Upper-level trajectories of dry air (Fig. 1a) originatedat upper levelsand to the northeast of the low-level TCS025 disturbance. These trajectories were related to the upper-tropopsheric cyclonic cell that contained cold, dry, sinking air. At lower levels (Figs. 1b,c), airflow into TCS025 originated from the west as part of the low-level monsoon trough. These air parcels provided a source of moisture to the low-level circulation of TCS025. Therefore, the nondevelopment of TCS025 was related to upper-level conditions that provided a source of dry air and weakened the favorable convective environment that previously existed in TCS025.

IMPACT/APPLICATIONS

At the time of the TCS-08 field experiment, it was uncertain whether the TCS025 disturbance would experience development. The numerical experiments presented in this study suggest that the proper representation of microphysical processes (and boundary layer processes) in numerical models is critical if storm development or non-development is to be forecast accurately, especially for systems similar to TCS025 that are sensitive to the nature of the precipitation processes.

The research being conducted on the comprehensive data sets gathered during the TCS-08 field program will result in increased accuracy associated with the prediction of tropical cyclone formation, intensification, and structural changes. These improvements will be defined in part through improved numerical simulations using high-resolution models such as the Coupled Ocean Atmosphere Mesoscsale Prediction System – Tropical Cyclone (COAMPS-TC). Additionally, the unique observations of the air-ocean conditions in the environment of mature tropical cyclones over the western North Pacific provide a unique capability to identify the relative roles of environmental factors on tropical cyclone intensity change.

TRANSITIONS

Following the compilation and analysis of the wide range of TCS-08 data sets, research results that identify factors responsible for the variability in tropical cyclone formation, intensification, and structure change will transition into a variety of products that will benefit operational forecasting of these tropical cyclone characteristics. These may be stand-alone products, satellite-based products, improvements to numerical models, etc. Final transition of the research will result in increased predictability associated with tropical cyclones that impact operations of the U.S. Navy across the western North Pacific

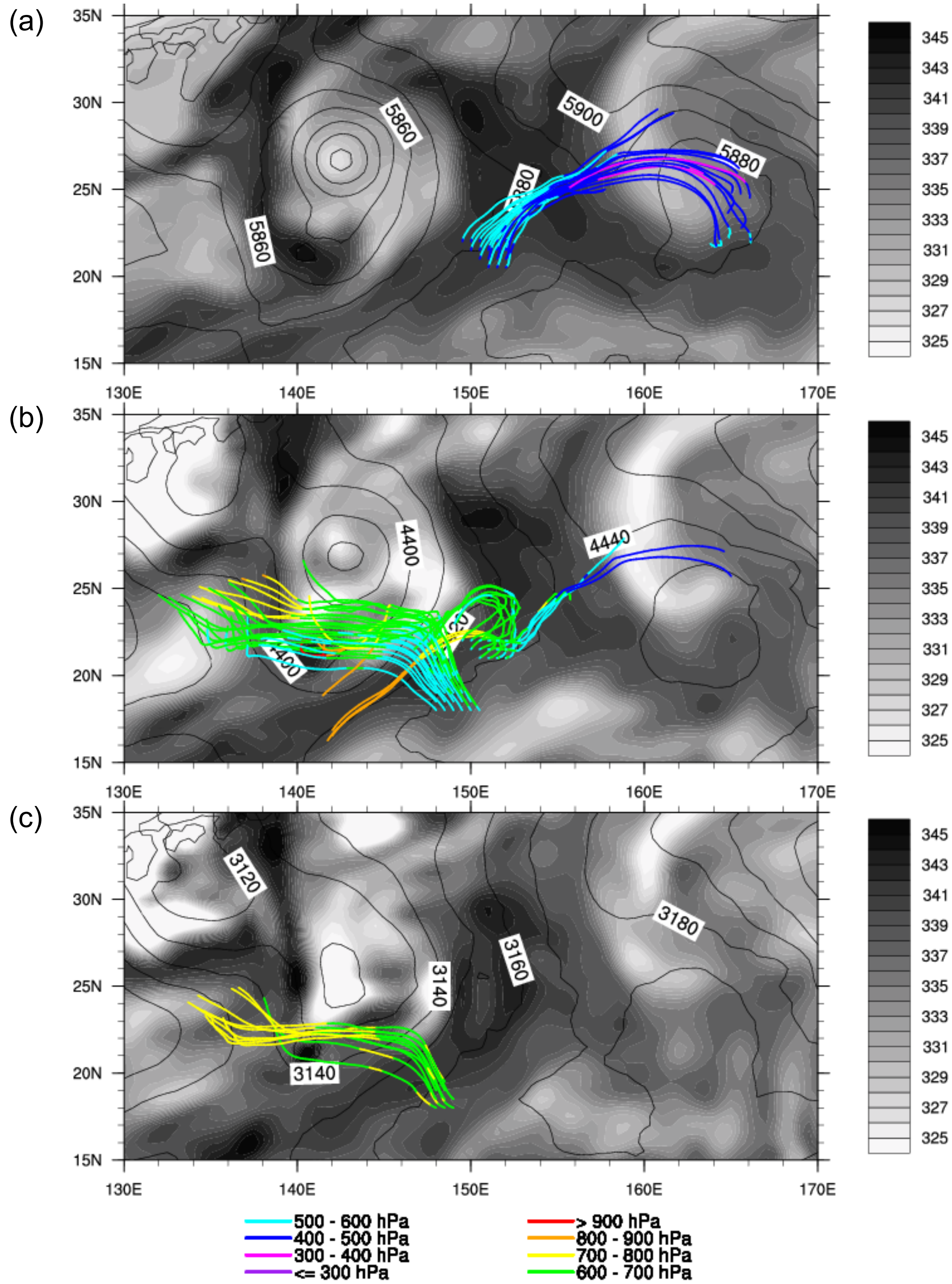

Figure 1. Equivalent potential temperature (K, shading) and geopotential height (m, contours) at 0000 UTC 25 August from the CFSR reanalysis at (a) 500 hPa, (b) 600 hPa and (c) 700 hPa. Colored lines correspond to 72-h back trajectories selected from grid points within the boxed region of 18-22°N, 148-152°E at (a) 500 hPa, (b) 600 hPa, and (c) 700 hPa in which the relative humidity at the ending time of 0000 UTC 28 August was < 70 %. Colored segments of trajectory lines indicate pressure levels in panel (c) inset.

RELATED PROJECTS

The analysis of tropical cyclone sturcture and intensity changes is being conducted in relation to several other projects sponsored by ONR Marine Meteorology. One project titled NASA Hurricane and Severe Storm Sentinel (HS3) Observations for Testing Environmental Control of Hurricane Formation and Intensification (N0001412WX21567) is examining data obtained during Hurricane and Severe Storms Sentinel experiment. The relationships among tropical cyclone structure and intensity changes to upper-level outflow is being examined in the project titled Tropical Cyclone Intensity and Structure Changes in relation to Tropical Cyclone Outflow (N0001413AF00002).

PUBLICATIONS

Penny, Andrew B., 2013: Observations and high-resolution numerical simulations of a non-developing tropical disturbance in the western North Pacific. PhD Disstertation. Naval Postgraduate School, Monterey, CA. 323 pp. [Available at http://calhoun.nps.edu]